THE FIRST BEINGS

Being a Natural Philosophical Treatise on the Origin of Life, the Chemistry of Emergence, and the Last Universal Common Ancestor

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Made by Eleven Eight Three

I. THE BOUNDARY CONDITIONS

1.1 The Hadean Earth

The natural philosopher begins with the planet. The Hadean eon, from 4.6 to 4.0 billion years ago, is the period during which life is thought to have emerged. The Earth was hot, bombarded by asteroids, and possessed a reducing or neutral atmosphere containing CO2, N2, H2O, and possibly H2, with trace amounts of CO, CH4, and NH3. The presence of liquid water is established by zircon crystals dated to 4.4 billion years ago. See Mojzsis, S.J. et al. (2001). 'Evidence for Life on Earth before 3,800 Million Years Ago.' Nature, 384, 55-59; and Valley, J.W. et al. (2002). 'A Cool Early Earth.' Geology, 30(4), 351-354.

The moon was closer, producing stronger tides. The day was shorter, perhaps 6 hours. The magnetic field was nascent. The crust was thin, volcanic, and fractured. These are not speculations; they are derived from isotopic dating, mineralogy, and orbital mechanics.

1.2 The Energy Sources

Life requires disequilibrium: an energy gradient to drive chemistry. The Hadean Earth offered multiple gradients. (1) Geothermal: alkaline hydrothermal vents on the seafloor released hydrogen, methane, ammonia, and hydrogen sulfide into ocean water. See Kelley, D.S. et al. (2001). 'An Off-Axis Hydrothermal Vent Field near the Mid-Atlantic Ridge at 30 degrees N.' Nature, 412, 145-149. (2) Solar: UV radiation at wavelengths below 200 nm can photolyze water and drive prebiotic synthesis. (3) Tidal: the mechanical shearing of coastal pools by the nearby moon. (4) Impact: asteroid strikes delivered energy, minerals, and possibly organic molecules. See Chyba, C. & Sagan, C. (1992). 'Endogenous Production, Exogenous Delivery and Impact-Shock Synthesis of Organic Molecules: An Inventory for the Origins of Life.' Nature, 355, 125-132.

The natural philosopher notes: no single energy source is proven to be the exclusive driver. But the existence of multiple sustained gradients is a boundary condition, not a hypothesis.

1.3 The Inventory of Molecules

Before life, there was chemistry. The Miller-Urey experiment of 1953 demonstrated that electric discharge in a reducing atmosphere of CH4, NH3, H2O, and H2 produces amino acids, hydroxy acids, and other organic compounds. See Miller, S.L. (1953). 'A Production of Amino Acids under Possible Primitive Earth Conditions.' Science, 117(3046), 528-529. While the precise atmospheric composition of early Earth is now debated (it may have been less reducing than Miller and Urey assumed), the core finding holds: energy input into simple gas mixtures generates biomolecules.

Subsequent work has expanded the inventory. Formamide, hydrogen cyanide (HCN), and cyanoacetylene have been shown to produce nucleobases, amino acids, and sugars under plausible prebiotic conditions. See Sutherland, J.D. (2016). 'The Origin of Life -- Out of the Blue.' Angewandte Chemie International Edition, 55(1), 104-121. Paternò-Büchi reactions can generate ribose from simple aldehydes. The natural philosopher concludes: the molecular precursors of life were present. This is a fact.

II. THE CHEMISTRY OF EMERGENCE

2.1 The Iron-Sulfur World

Günter Wächtershäuser proposed that life began on mineral surfaces -- specifically iron-sulfur minerals like pyrite (FeS2) -- where carbon fixation could occur via the reductive citric acid cycle, driven by the redox gradient between ferrous iron and hydrogen sulfide. See Wächtershäuser, G. (1988). 'Before Enzymes and Templates: Theory of Surface Metabolism.' Microbiological Reviews, 52(4), 452-484. The theory posits that mineral surfaces acted as both catalyst and scaffold: they organized molecules in two dimensions, concentrated them, and provided the reducing power to build carbon skeletons from CO2.

The theory makes testable predictions. Huber and Wächtershäuser (1997) demonstrated that amino acids can be synthesized from CO and H2S on NiS/FeS surfaces at 100 C and 100 bar -- conditions relevant to hydrothermal systems. See Huber, C. & Wächtershäuser, G. (1997). 'Activated Acetic Acid by Carbon Fixation on (Fe,Ni)S under Primordial Conditions.' Science, 276(5310), 245-247. This is experimental evidence, not speculation.

2.2 The Alkaline Vent Theory

Michael Russell and William Martin proposed that life originated in alkaline hydrothermal vents on the seafloor -- not the black smoker volcanic vents, but cooler (40-90 C), off-axis vents formed by the reaction of seawater with ultramafic rock. These vents produce porous chimney structures of metal sulfides and carbonates, with steep pH gradients (alkaline interior, acidic ocean) and redox gradients (H2-rich interior, CO2-rich ocean). See Russell, M.J. & Martin, W. (2004). 'The Rocky Roots of the Acetyl-CoA Pathway.' Trends in Biochemical Sciences, 29(7), 358-363.

The theory is physically well-motivated. The vents provide: (1) sustained chemical disequilibrium, (2) microcompartments (pores) for concentration and containment, (3) catalytic mineral surfaces, (4) a continuous supply of H2 and CO2, and (5) an electrochemical proton gradient analogous to the chemiosmotic gradient used by modern life. See Lane, N. & Martin, W.F. (2012). 'The Origin of Membrane Bioenergetics.' Cell, 151(7), 1406-1416. The natural philosopher marks this as a leading hypothesis with strong geological and biochemical support, though not proven as the actual site of origin.

2.3 Wet-Dry Cycles

David Deamer and Bruce Damer have argued that the origin of life required not deep-sea vents but terrestrial hot springs -- specifically, fluctuating pools on volcanic landscapes subjected to wet-dry cycles. The cycles concentrate dilute organic molecules, drive polymerization by dehydration, and select for stable structures. See Damer, B. & Deamer, D. (2020). 'The Hot Spring Hypothesis for an

Origin of Life.' Astrobiology, 20(4), 429-452.

Experimental support: when nucleotides are subjected to repeated wet-dry cycles in the presence of lipids, they form RNA-like polymers encapsulated in vesicles. The cycling creates compartments, concentrates reactants, and drives the formation of phosphodiester bonds. See Deamer, D. (2017). 'The Role of Lipid Membranes in Life's Origin.' Life, 7(1), 5. This is a competing hypothesis to the vent theory, not a refutation. The natural philosopher notes that both could be true: chemistry may have begun in vents and been completed in pools.

2.4 The Phosphorylation Problem

A persistent difficulty in origin-of-life research is the activation of phosphate. Modern life uses triphosphates (ATP, GTP) as energy currency. How did prebiotic chemistry achieve phosphorylation without enzymes? Recent work by Kee et al. and others has shown that schreibersite (Fe,Ni)3P, a mineral found in meteorites, can release reactive phosphide that phosphorylates organic molecules in alkaline hydrothermal conditions. See Kee, T.P. et al. (2013). 'On the Prebiotic Potential of Reduced Oxidation State Phosphorus Compounds.' In: Origins of Life: The Primal Self-Sufficiency, 87-112. Springer.

Additionally, the proton gradients in alkaline vents can drive the formation of pyrophosphate (the simplest activated phosphate) from orthophosphate without biological enzymes. See Martin, W. & Russell, M.J. (2007). 'On the Origins of Cells: A Hypothesis for the Evolutionary Transitions from Abiotic Geochemistry to Chemoautotrophic Prokaryotes, and from Prokaryotes to Nucleated Cells.' Philosophical Transactions of the Royal Society B, 358, 59-85. The natural philosopher records: the energy problem and the phosphate problem may have the same solution -- the geochemistry of vents.

III. THE CONTAINER

3.1 Protocells and Lipid Vesicles

Life requires compartmentalization. Without a boundary, useful molecules diffuse away and parasites consume the products of others' labor. Jack Szostak and colleagues have demonstrated that simple fatty acids and related amphiphiles self-assemble into vesicles in aqueous solution. These vesicles grow, divide, and encapsulate RNA. See Zhu, T.F. & Szostak, J.W. (2009). 'Coupled Growth and Division of Fatty Acid Vesicles.' Journal of the American Chemical Society, 131(15), 5705-5713.

The vesicles are not alive. But they exhibit lifelike properties: they maintain internal chemistry distinct from the external environment, they grow by incorporating fatty acids from the surroundings, and they divide when subjected to shear forces. The natural philosopher notes: this is a demonstration of principle. Compartmentalization is physically spontaneous under prebiotic conditions.

3.2 The Pore-Metal-Organic Framework

In the alkaline vent theory, the first compartments were not lipid vesicles but mineral pores -- microscopic chambers in the vent chimney walls, 10-100 micrometers in size, lined with catalytic FeS and NiS minerals. These pores functioned as electrochemical flow reactors: alkaline hydrothermal fluid flowed through the pore, meeting acidic ocean water at the interface, maintaining a steady proton gradient across the mineral wall. See Russell, M.J. et al. (2014). 'The Drive to Life on Wet and Icy Worlds.' Astrobiology, 14(4), 308-343.

The natural philosopher observes: these compartments are not alive. They are physical structures that perform a subset of cellular functions (concentration, catalysis, energy transduction) without genes or metabolism. They are the scaffold upon which metabolism could have been built. The transition from mineral pore to lipid vesicle is a major unsolved problem.

3.3 The Transition to Membranes

How did life move from mineral compartments to lipid membranes? One proposal is that short-chain fatty acids, synthesized abiotically or delivered by meteorites (as in the Murchison meteorite), inserted into mineral pores and gradually formed a lipid monolayer, then bilayer, on the mineral surface. The lipid layer eventually closed into a vesicle, capturing the mineral-bound chemistry inside. See Mansy, S.S. et al. (2008). 'Template-Directed Synthesis of a Genetic Polymer in a Model Protocell.' Nature, 454, 122-125.

Another proposal is that peptides formed first and acted as primitive surfactants, stabilizing membranes before lipids dominated. See Black, R.A. et al. (2013). 'Nucleobases Bind to and Stabilize Aggregates of a Prebiotic Amphiphile, Providing a Viable Mechanism for the Emergence of Protocells.' Proceedings of the National Academy of Sciences, 110(33), 13272-13276. The natural philosopher marks all these transitions as speculative but physically plausible.

IV. THE INFORMATION

4.1 The RNA World

The RNA world hypothesis, articulated by Walter Gilbert in 1986 and developed by many others, proposes that RNA was both the genetic material and the catalyst of early life, before DNA and proteins took over these roles. RNA can store information (like DNA) and catalyze reactions (like proteins). See Gilbert, W. (1986). 'The RNA World.' Nature, 319, 618. Ribozymes -- catalytic RNA molecules -- have been discovered in modern organisms and synthesized in the laboratory. See Cech, T.R. (1986). 'A Model for the RNA-Catalyzed Replication of RNA.' Proceedings of the National Academy of Sciences, 83(12), 4360-4363.

The hypothesis is supported by the fact that the ribosome -- the universal protein-synthesizing machine -- is a ribozyme. The catalytic core of the ribosome is RNA, not protein. This suggests that protein synthesis was invented by RNA. See Nissen, P. et al. (2000). 'The Structural Basis of Ribosome Activity in Peptide Bond Synthesis.' Science, 289(5481), 920-930. The natural philosopher records: the RNA world is the dominant hypothesis for the information system of early life, though the prebiotic synthesis of RNA remains difficult.

4.2 The Prebiotic Synthesis of RNA

RNA is complex. It requires a sugar (ribose), a nucleobase, and a phosphate, linked in the correct stereochemistry. The prebiotic synthesis of ribose from formaldehyde via the formose reaction is non-selective and produces many side products. However, recent work by Sutherland and colleagues has shown that ribonucleotides can be synthesized from cyanamide, cyanoacetylene, glycolaldehyde, and phosphate in a unified reaction network that bypasses free ribose. See Powner, M.W., Gerland, B., & Sutherland, J.D. (2009). 'Synthesis of Activated Pyrimidine Ribonucleotides in Prebiotically Plausible Conditions.' Nature, 459, 239-242.

This is a landmark result. It demonstrates that the building blocks of RNA can arise from a small set of simple precursors under conditions relevant to early Earth. The natural philosopher notes: this does not prove that RNA arose this way. But it removes a major objection to the RNA world hypothesis.

4.3 RNA Replication

For the RNA world to function, RNA must replicate. Laboratory experiments have produced RNA polymerase ribozymes that can synthesize RNA strands of up to 95 nucleotides. See Horning, D.P. & Joyce, G.F. (2016). 'Amplification of RNA by an RNA Polymerase Ribozyme.' Proceedings of the National Academy of Sciences, 113(35), 9786-9791. However, these ribozymes are complex (over 200 nucleotides) and unlikely to have arisen spontaneously. Simpler replicators may have existed but

have not yet been discovered.

An alternative is non-enzymatic RNA replication. Template-directed polymerization of activated nucleotides can occur on mineral surfaces or in eutectic ice phases. See Rajamani, S. et al. (2008). 'Lipid-Assisted Synthesis of RNA-like Polymers from Mononucleotides.' Origins of Life and Evolution of Biospheres, 38(1), 57-74. The natural philosopher marks RNA replication as a partially solved problem: we know it can happen, but not how it began.

4.4 Before RNA: The Pre-RNA World

Some researchers argue that RNA was too complex to be the first information polymer. Candidates for pre-RNA include peptide nucleic acid (PNA), threose nucleic acid (TNA), and glycerol nucleic acid (GNA). These have simpler backbones but can still form double helices and store information. See Eschenmoser, A. (1999). 'Chemical Etiology of Nucleic Acid Structure.' Science, 284(5423), 2118-2124. The natural philosopher notes: these are speculative alternatives. There is no experimental evidence that PNA or TNA existed on early Earth. They are proof-of-concept molecules.

V. LUCA: THE LAST UNIVERSAL COMMON ANCESTOR

5.1 What LUCA Was Not

LUCA was not the first organism. It was the most recent organism from which all extant life descends. There was a long history of evolution before LUCA. LUCA was not alone: it coexisted with other lineages that have since gone extinct. See Weiss, M.C. et al. (2016). 'The Physiology and Habitat of the Last Universal Common Ancestor.' Nature Microbiology, 1(9), 16116.

LUCA was not necessarily a single cell. It may have been a population of cells exchanging genes horizontally. The concept of a single ancestor is a statistical abstraction: the point in the phylogenetic tree where all branches converge. The natural philosopher warns against anthropomorphizing LUCA. It was a biochemical system, not a creature.

5.2 What LUCA Was

Comparative genomics allows us to infer LUCA's properties. Genes present in all three domains of life (Bacteria, Archaea, Eukaryota) were likely present in LUCA. Weiss et al. (2016) reconstructed 355 genes belonging to LUCA. The results indicate that LUCA was: (1) anaerobic, (2) H2-dependent, (3) thermophilic or hyperthermophilic, (4) capable of chemiosmosis (using proton gradients for ATP synthesis), (5) possessing the Wood-Ljungdahl pathway for carbon fixation, and (6) using the reverse Krebs cycle for biosynthesis. See Weiss et al. (2016), cited above.

These traits align closely with the alkaline vent hypothesis. LUCA's metabolism -- H2-dependent, CO2-fixing, proton-gradient-powered -- is exactly the metabolism that geochemistry can provide in alkaline vents. The natural philosopher notes: this is a strong convergence between phylogenetics and geochemistry. It does not prove the vent hypothesis, but it is consistent with it.

5.3 The Energy of LUCA

Lane and Martin argue that LUCA's core innovation was not genetics but energy transduction: the harnessing of natural proton gradients across lipid membranes to drive ATP synthesis. This required only a simple ATP synthase and a membrane -- both of which could have been prefigured by mineral pores. See Lane, N. & Martin, W.F. (2012). 'The Origin of Membrane Bioenergetics.' Cell, 151(7), 1406-1416. Once life could generate its own proton gradient (by pumping protons using electron transport chains), it was no longer dependent on geological gradients. It became free-living.

The natural philosopher records this as a pivotal transition: from geochemistry to biochemistry, from passive flow reactor to active metabolizer. The date is uncertain but constrained by the 3.8-3.5 billion year old stromatolite and microfossil evidence. See Schopf, J.W. et al. (2017). 'SIMS Analyses of the Oldest Known Assemblage of Microfossils Document Their Taxon-Correlated

Carbon Isotope Composition.' Proceedings of the National Academy of Sciences, 114(1), 53-58.

VI. A SPECULATIVE RECONSTRUCTION

6.1 The Scenario (Clearly Marked)

The following is a speculative synthesis, consistent with known facts but not proven by them. It is offered as a plausible narrative, not as history.

Stage 1 -- Geochemistry (4.4 to 4.0 Ga): Alkaline hydrothermal vents on the Hadean seafloor release H2, CH4, NH3, and H2S into CO2-rich ocean water. The pH gradient across vent pore walls drives the reduction of CO2 to simple organics (formate, acetate) on FeS and NiS mineral surfaces. Phosphide minerals from meteorites or the mantle provide activated phosphate. Wet-dry cycles in coastal pools concentrate these molecules and drive polymerization. See Martin, W. & Russell, M.J. (2003). 'On the Origins of Cells: A Hypothesis for the Evolutionary Transitions from Abiotic Geochemistry to Chemoautotrophic Prokaryotes.' Philosophical Transactions of the Royal Society A, 358, 59-85.

Stage 2 -- Proto-Metabolism (4.0 to 3.8 Ga): Within mineral pores, an autocatalytic network of reactions emerges. Acetyl thioesters (activated acetate) form spontaneously and enter primitive versions of the reverse Krebs cycle and the Wood-Ljungdahl pathway. The network is not encoded; it is maintained by continuous flow and mineral catalysis. Lipids and peptides begin to line the pore walls, forming a primitive membrane. See Russell, M.J. et al. (2014), cited above.

Stage 3 -- The RNA World (3.8 to 3.5 Ga): Ribonucleotides, synthesized in vent fluids or delivered by meteorites, polymerize into short RNA strands. Some strands fold into ribozymes that catalyze their own replication or the synthesis of other RNAs. The first genetic information is not a code for proteins; it is a code for replication. Vesicles containing RNA and mineral catalysts bud off from the vent walls. See Szostak, J.W. (2017). 'The Narrow Road to the Deep Past: In Search of the Chemistry of the Origin of Life.' Angewandte Chemie, 56(37), 11037-11043.

Stage 4 -- The Darwinian Threshold (3.5 to 3.0 Ga): RNA replicators become enclosed in lipid membranes with sufficient fidelity that genotype and phenotype are coupled. Natural selection begins to operate on variation in replication accuracy and catalytic efficiency. Proteins, initially synthesized by ribozymes, take over catalytic roles. DNA, more stable than RNA, replaces RNA as the genetic archive. LUCA emerges as the common ancestor of the three domains. See Koonin, E.V. (2007). 'The Biological Big Bang Model for the Major Transitions in Evolution.' Biology Direct, 2, 21.

The natural philosopher marks each stage with its evidentiary status: Stage 1 is supported by geochemistry and thermodynamics. Stage 2 is supported by analog chemistry but not by direct evidence. Stage 3 is supported by ribozyme experiments but not by prebiotic synthesis of complex replicators. Stage 4 is supported by phylogenomics but not by fossils.

6.2 The First Beings

If the scenario is correct, the first beings were not cells. They were mineral-bound chemical networks -- flow reactors in vent pores, maintaining steady-state disequilibrium by consuming geochemical gradients. They had no genes. They had no membranes of their own. They were patterns of catalysis sustained by the Earth's heat and chemistry.

The first beings with heredity were RNA replicators in lipid vesicles -- perhaps 100-1000 nucleotides long, error-prone, parasitized by shorter, faster-replicating strands. They were not organisms in the modern sense. They were chemical systems with two properties: they could replicate, and they could catalyze. The natural philosopher notes: this is a minimal definition of life, but it is sufficient. Heredity plus catalysis, enclosed in a boundary, subject to selection.

The first beings we would recognize as cells were LUCA's contemporaries or descendants: H2-eating, CO2-fixing, proton-gradient-powered chemolithoautotrophs living in or near hydrothermal systems. They were anaerobic, thermophilic, and simple. They were the foundation of everything that followed.

VII. WHAT WE DO NOT KNOW

7.1 The Gaps

The natural philosopher ends with honesty. The following questions remain unanswered by current science:

(1) How did homochirality emerge? Modern biomolecules are exclusively left-handed (amino acids) or right-handed (sugars). Prebiotic chemistry produces racemic mixtures. The origin of single-handedness is unknown. See Blackmond, D.G. (2010). 'The Origin of Biological Homochirality.' Cold Spring Harbor Perspectives in Biology, 2(5), a002147.

(2) How did the first RNA replicator arise? The simplest known ribozyme polymerase is ~200 nucleotides. The probability of its spontaneous assembly from random monomers is vanishingly small. There may have been simpler replicators, or mineral-assisted pathways, or a pre-RNA world. None of these has been demonstrated. See Joyce, G.F. (2002). 'The Antiquity of RNA-Based Evolution.' Nature, 418, 214-221.

(3) How did the genetic code originate? The mapping of 64 codons to 20 amino acids is universal but arbitrary. There is no chemical necessity for the specific assignments. The code may have evolved from simpler codes (e.g., a two-letter code for a subset of amino acids), but the pathway is speculative. See Koonin, E.V. & Novozhilov, A.S. (2009). 'Origin and Evolution of the Genetic Code: The Universal Enigma.' IUBMB Life, 61(2), 99-111.

(4) Was there a single origin or multiple origins? All extant life shares a common biochemistry, suggesting a single origin or a rapid takeover by one lineage. But we cannot rule out independent origins that were outcompeted or merged. See Doolittle, W.F. (2000). 'The Nature of the Universal Ancestor and the Evolution of the Proteome.' Current Opinion in Structural Biology, 10(3), 355-358.

(5) When did life begin? The oldest confirmed microfossils are ~3.5 billion years old. Carbon isotope evidence suggests biological carbon fixation as early as 3.8 billion years. The Hadean zircons indicate liquid water at 4.4 billion years. The window is wide: 4.4 to 3.5 Ga. We do not know where in that window life emerged.

7.2 The Natural Philosopher's Conclusion

The first beings were not miracles. They were chemistry, organized by energy gradients, enclosed by physics, and selected by the logic of replication. They emerged from a planet that was hot, wet, and chemically active. They were sustained by the Earth's interior heat and the disequilibrium between rock and water.

We do not know the exact path. But we know the boundary conditions, the inventory of molecules, the possible energy sources, the mechanisms of compartmentalization, and the properties of the last common ancestor. The gaps are real. But the scaffold is solid.

The natural philosopher does not claim to have seen the first beings. The natural philosopher claims to have measured the world in which they must have lived, and to have described the chemistry they must have performed. The rest is speculation -- but speculation anchored to fact.

* * *

THE COLOPHON

The first beings were chemistry.

The first chemistry was geology.

The first geology was heat.

Heat is the engine of nothing becoming something.

Now measure. The first cell is dust, organized by a gradient.

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